



Applications of GPS Provided Time and Frequency and Future

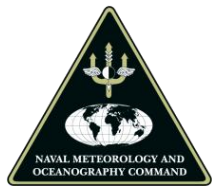
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GPS Timing Operations Division Chief

August 14, 2012

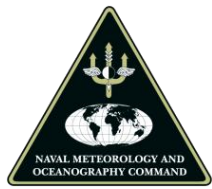
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Outline



- GPS Provided Timing Service
 - History of UTC and GPS
 - Accuracy of GPS timing service
- Precise Time Requirements
 - Communication Networks
 - Power Grid
 - Banking
 - Scientific
- GPS Monitoring
- Filters and Effect on GPS Signals



DoD Directive 4650.05 and 4650.07 (2012)



- The Secretary of the Navy shall direct the U.S. Naval Observatory to:
 - Develop and maintain the standards for Precise Time and Time Interval (PTTI) services, earth orientation parameters, and the celestial reference frame for the DoD Components
 - Provide representation to PNT committees and working groups, as necessary
 - Serve as the DoD PTTI Manager for all DoD systems

*Maintain the Master Clock for DoD and
US government PNT systems*

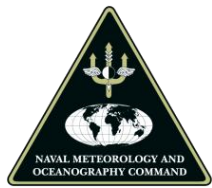


UTC Time from GPS



- GPS Time (GPS Internal Navigation Time Scale) is formed by creating a virtual clock “paper clock” through the weighed average of most GPS satellite and ground station clocks.
- GPS Time, is not adjusted for leap seconds and is not intended to be used for timing applications. GPS time repeats ever 19.6 years, Epoch #1 started counting whole seconds on Jan 6, 1980. GPS time Epoch #2 started on Aug 22, 1999 and Epoch #3 will start in 2019.
- Applying the sub-frame 4, page 18, corrections in the GPS message allows the timing user to recover UTC time traceable to UTC(USNO). CNAV and MNAV have improved versions of his correction defined.

NOTE: The timing calibration bias of the GPS internal navigation time scale is physically established at the United States Naval Observatory (USNO). USNO is responsible for measuring and maintaining the calibration of both the GPS internal navigation time scale and the UTC time products produced by GPS.



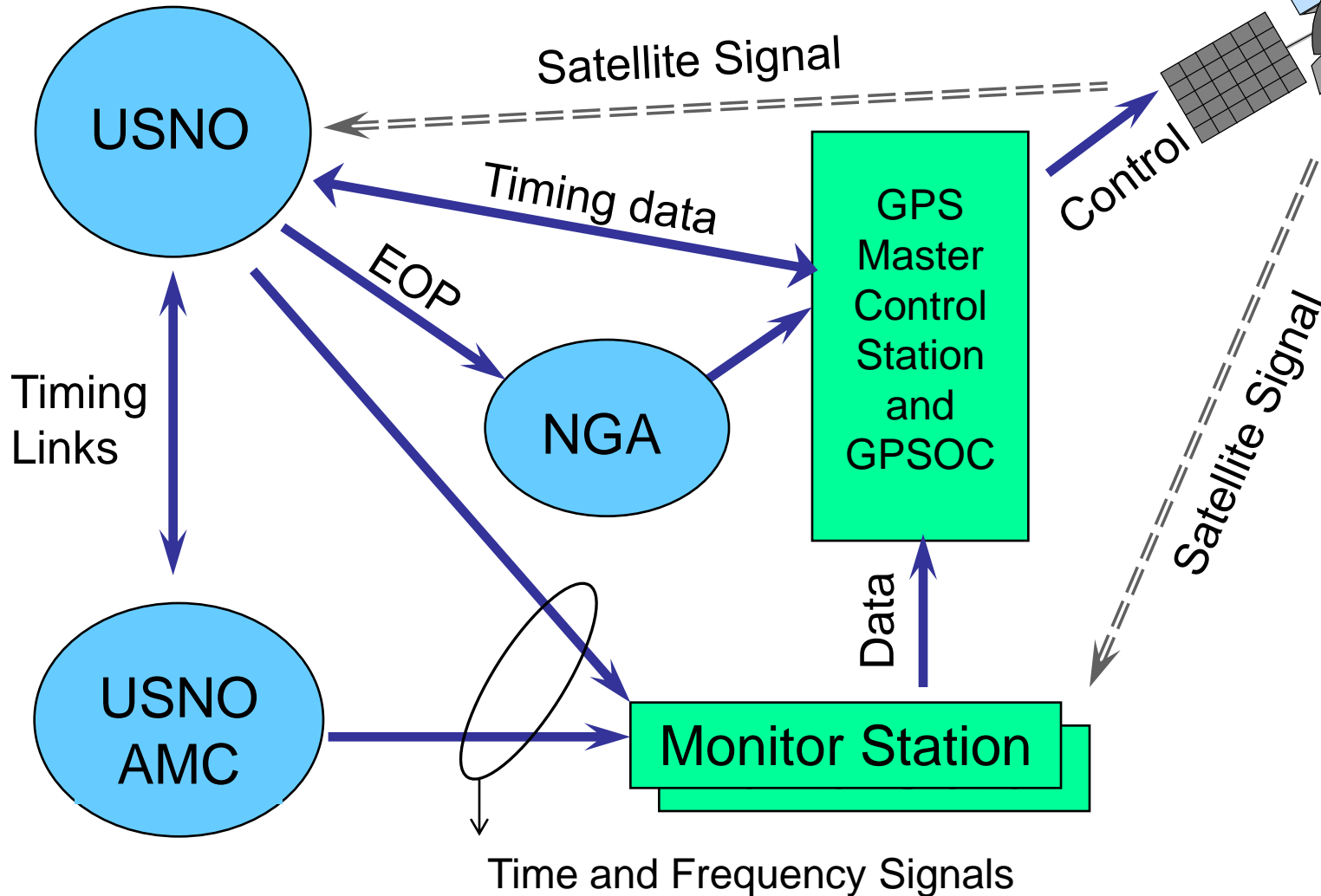
USNO Time Monitor for GPS



- USNO employs a bank of specialized SAASM GPS time monitor receivers located at USNO in Washington DC and at the USNO AMC in Col Springs
- The USNO time monitor receivers are used to make carefully calibrated measurements of each GPS SV clock relative to UTC(USNO)
- These observations are filtered, averaged and provided to 2SOPS (via the USNO to GPS ICD-202 interface) to produce a daily correction which is broadcast to the user in the GPS NAV msg.



USNO Contribution to GPS





Existing USNO GPS Operations



**SAASM
Units**

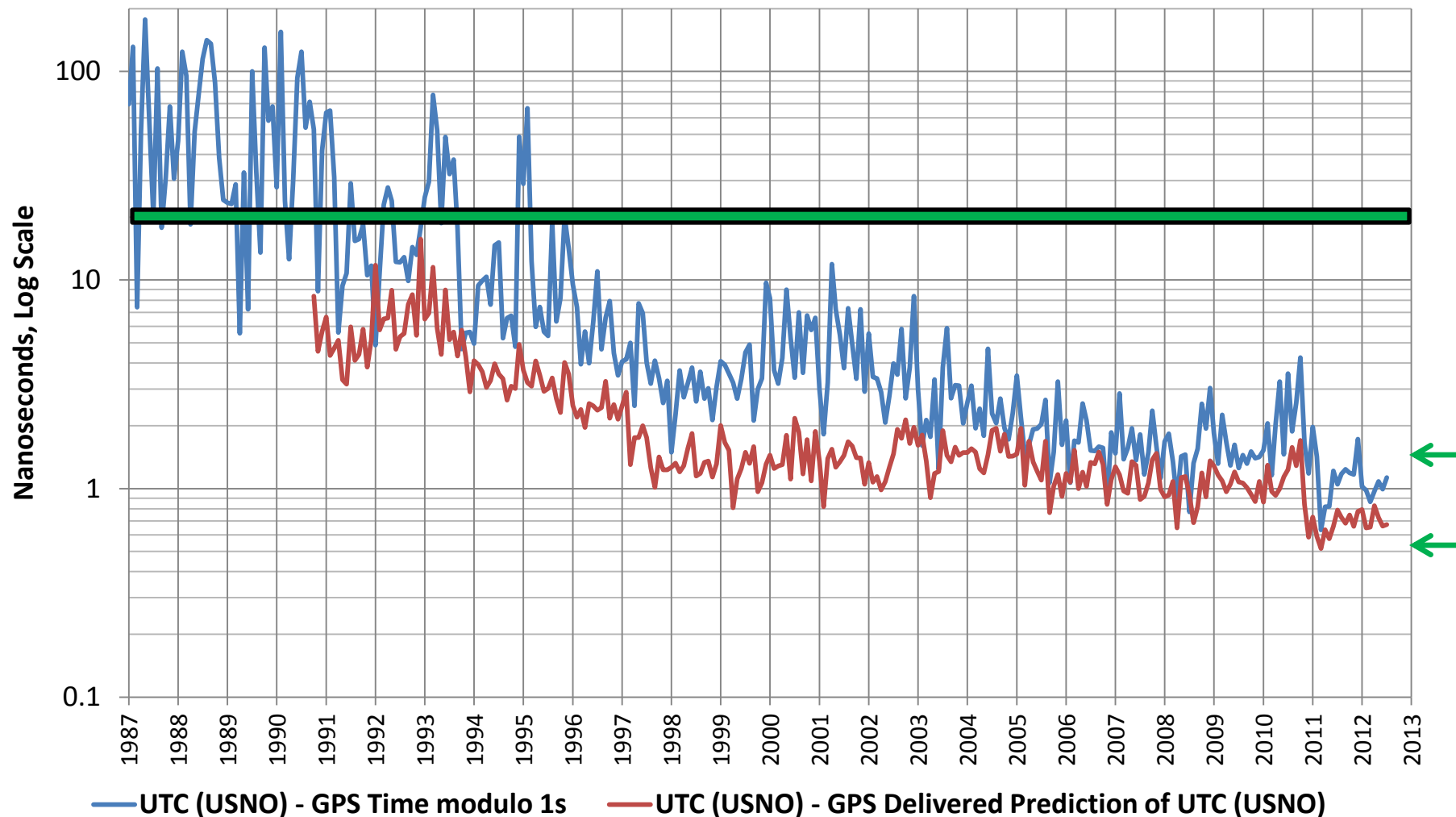
**Legacy
PPS-SM
Units**

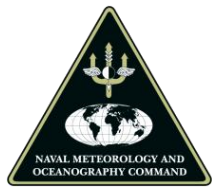


GPS Timing Service During the Past 25 Years



GPS Monthly Standard Deviations as measured by USNO

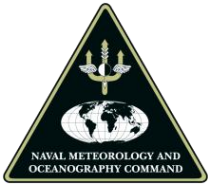




Universal Coordinated Time (UTC)



- In April 1875, the US Government and sixteen other countries signed the “Convention of the Metre” which is a diplomatic treaty now signed by fifty-six nations.
- This treaty gives authority to the Bureau International des Poids et Mesures (BIPM) to act in matters of coordinating world metrology.
- As such the BIPM acts as the coordinator for the standardization of world time (UTC).



BIPM and UTC Timing – Overview



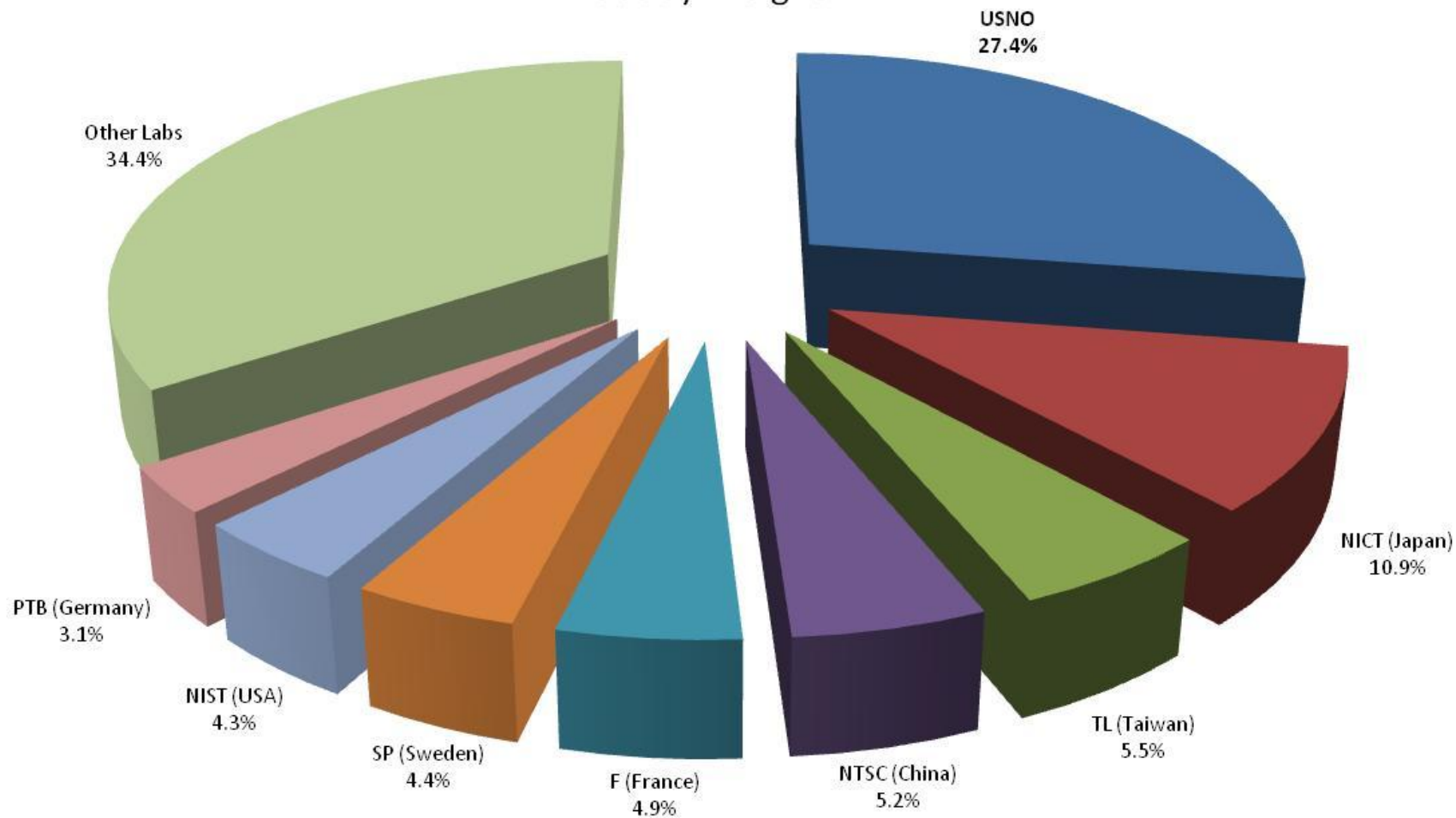
- The BIPM does not maintain a real-time “standard” clock.
 - It computes a monthly weighted average of clock data from contributing NMI timing laboratories (USNO, NIST for United States)
 - It reports this data back to each of the contributing NMI laboratories many weeks later (circular T).
 - Real-time access to UTC is available only through physical clocks at NMI contributing laboratories.
- USNO contributes a large weight to international time and currently maintains the best real-time representation of UTC.
 - UTC(USNO) is usually maintained within 10 ns of UTC
 - All world timing centers have agreed to keep their time-scales closely synchronized with UTC



UTC Laboratory Contributions



Labs by Weight



GPS Provided Precise Time and Time Interval (PTTI) Support



Communications



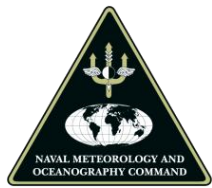
Power Grid



Banking



Scientific



Early Usage of GPS Timing Service



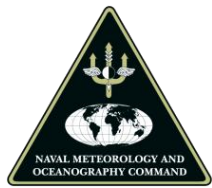
- During the initial development phase of GPS Block I (1970's and 1980's) and well before GPS IOC/FOC the commercial timing industry embraced GPS to support commercial applications.
- By the late 1980's hundred's of GPS timing receiver were in use at commercial telecommunication sites around the world.
- By the time GPS reached its full operational status in April 1995 the timing services provided by GPS were being used as a foundation for the telecommunication industry worldwide.
- Today there are estimated to be a half million+ timing GPS receivers supporting industry world wide.



Telecommunication



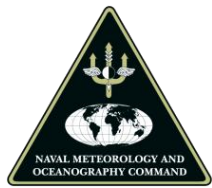
- Telecommunication Industry makes wide use of GPS provided timing supporting a variety of applications
 - Switched Telephone Networks (1E-11 Frequency) as a primary reference clock
 - Cellular Telephone System (microsecond timing) used to synchronize cell sites allowing seamless switching
 - Network Time Protocol (millisecond) supporting application level usage of accurate time
 - IP based applications like streaming audio, video
 - Precise Timing Protocol (sub-microsecond across a facility)



Cellular Telephones and GPS Timing



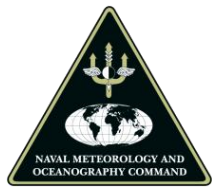
- Many different types of third and fourth generation cellular telephone network exist today, most with some degree of dependence on precise time.
 - CDMA requires precise time (microseconds) and uses GPS timing to coordinate time between base stations.
 - GSM has less stringent timing requirements, but third and fourth generation requirements are trending toward reliance of GPS timing.
- There are an estimated 500,000 cellular base stations in operations globally, most with embedded GPS timing equipment.



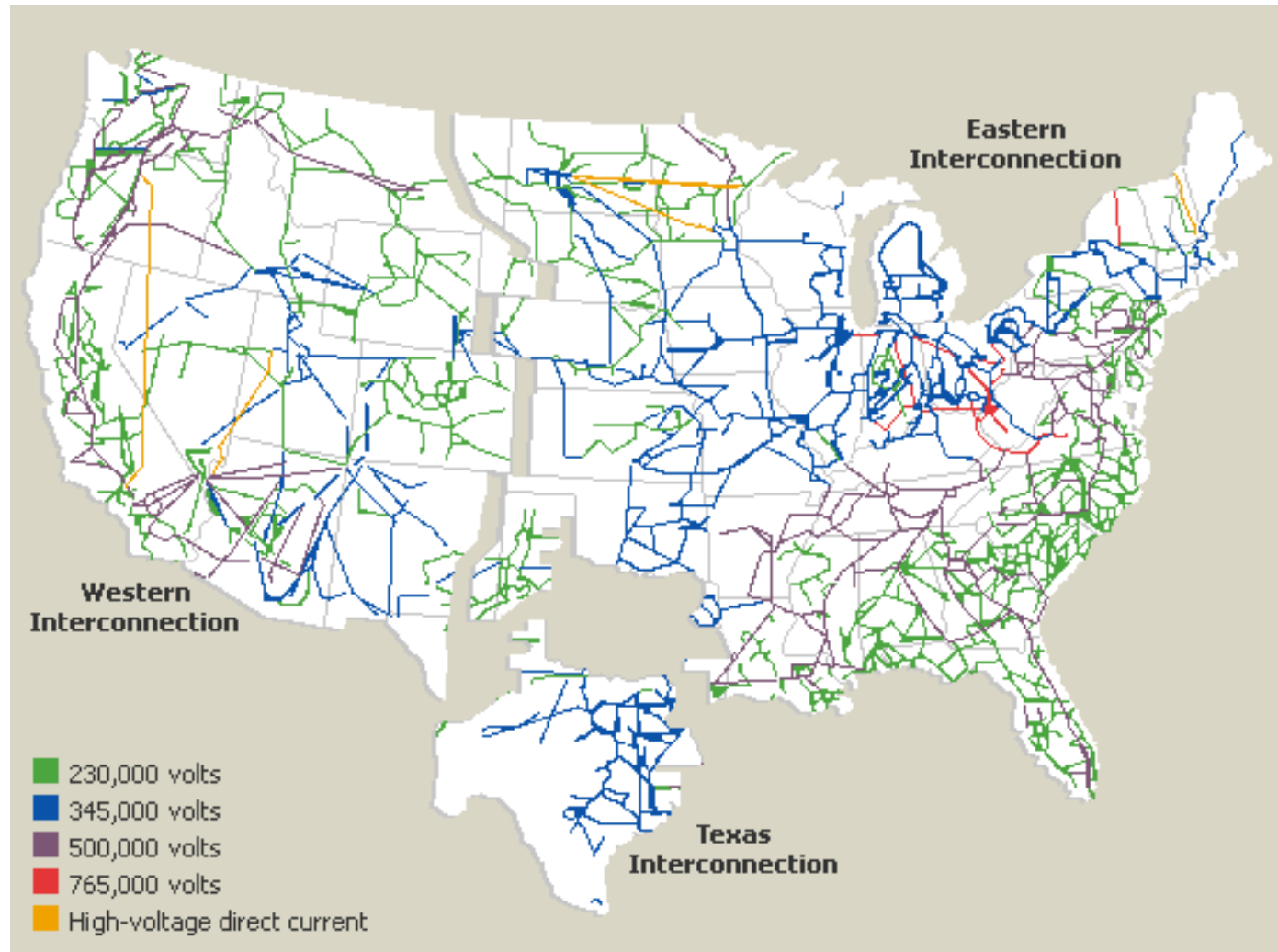
Power Grid



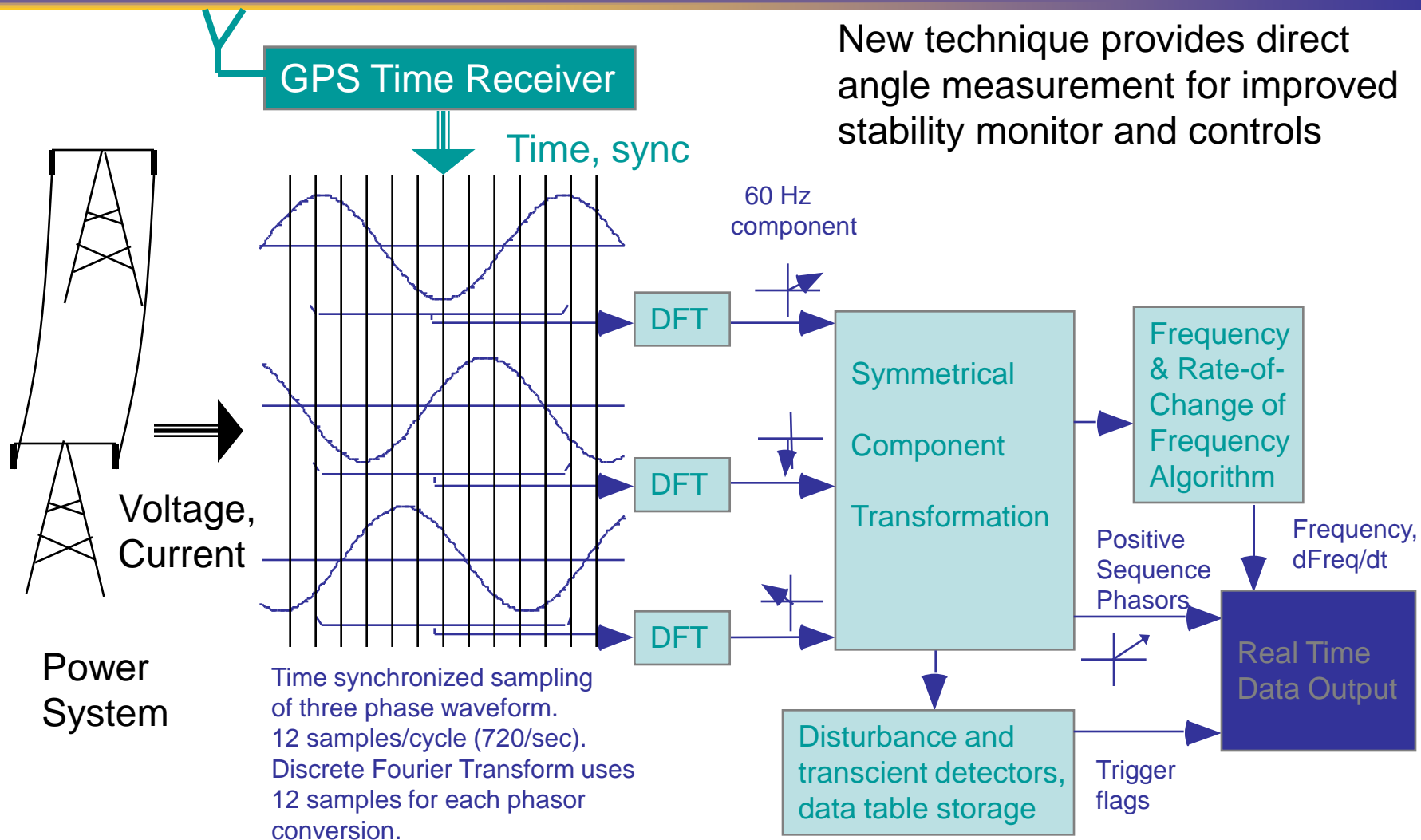
- The world power grid requires synchronization of the alternating current (50/60 Hz) which historically has been accomplished by adjusting the phase at local power generating plants to match the overall power grids phase.
- Small phase inaccuracy will reduce efficiencies and larger errors may result in damage to equipment and power outages.
- GPS based Phasor synchronization equipment is starting to be installed globally resulting in:
 - Higher efficiency in power transmission
 - Fewer black outs
 - Better fault isolation
- Power line fault isolation is often accomplished using GPS timing to measure the distance to a break in a power line, which greatly reduces the time to find the break and to restore service



US Power Grid

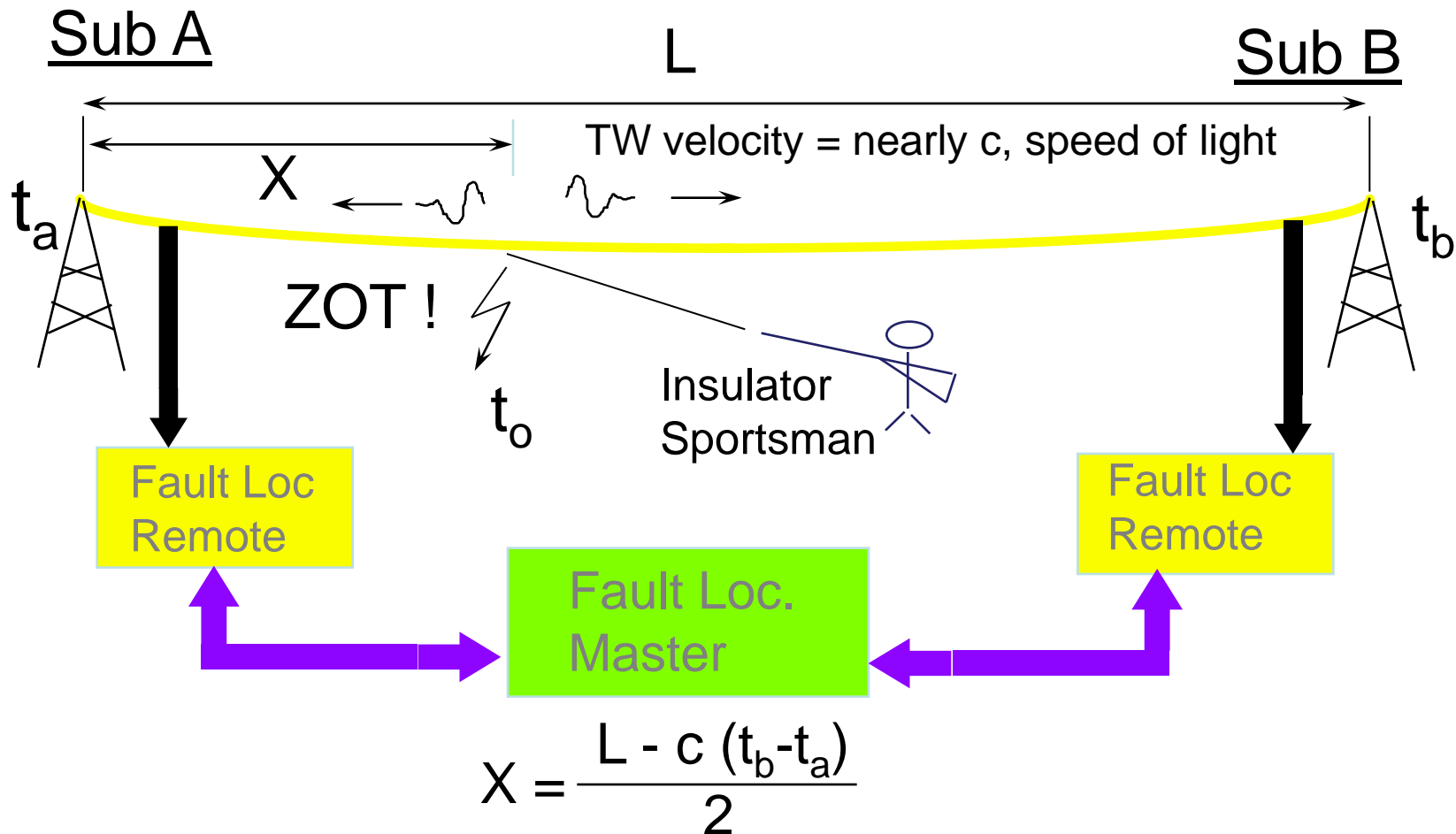


Phasor Measurement



Traveling Wave Fault Locator

FL remotes provide microsecond accuracy TW timetags at substations using GPS timing. Timetags are compared in the master to determine fault location.

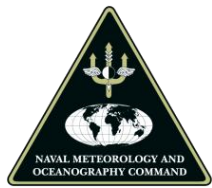




Summary of Timing Requirements for Power Grid

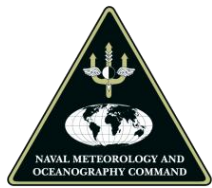


System Function	Measurement	Optimum Accuracy	Time Sources
TW Fault Locator	300 m (line span)	1 μ s	GPS
Relaying (line protection)	1000 m	3 μ s	GPS
Phasor Measurement	+/- 0.1 degree	4.6 μ s (60 Hz)	GPS
Networked Controls	+/- 0.1 degree	4.6 μ s	GPS
Stability Controls (RAS,etc)	+/- 1 degree	46 μ s	GPS
Event recording (DFR, etc)	Record compare	1 ms	GPS
Generation Control (AGC)	Freq, time error	10 ms	GPS, Net
Scheduling, reservation	Time of day	0.5 sec	GPS, Net



Banking and other Financial Transactions

- With billions of financial transactions per day and the emergence of fully automated computer trading, precisely timing of trades are critical.
- An inaccurate time stamps could result in unfair advantage being gained and loss of revenue.
- Today time stamp traceability requirements are at the one second level, and within a few years millisecond timing will be required to support high speed computer trading.

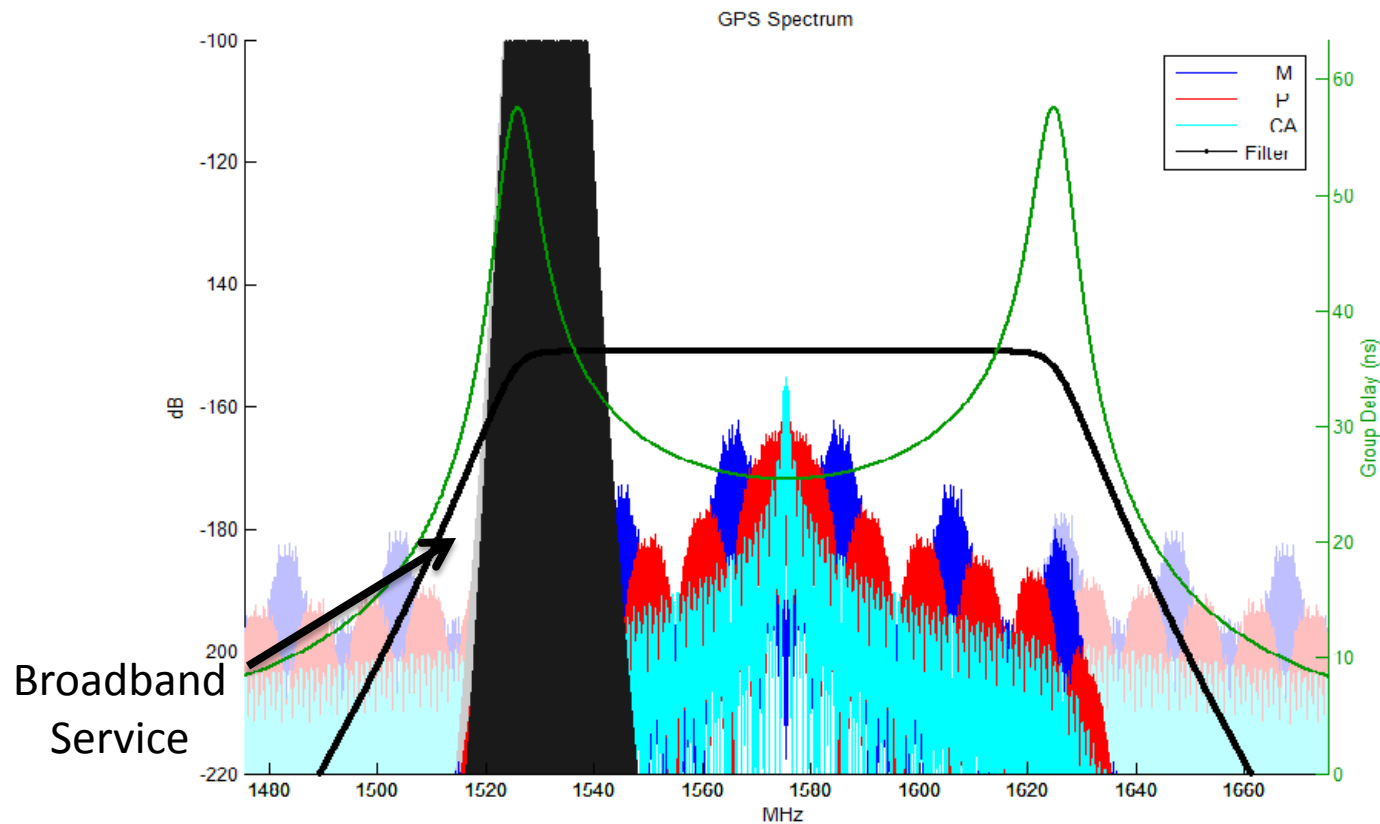


Scientific Application of PTTI

- Deep Space Tracking Network (DSN) and Very Long Baseline Interferometry (VLBI) needs very stable frequency and uses MASER clocks and carrier phase GPS to link various sites.
- CERN faster than light neutrinos experiment, flaw do to calibration error (lose cable). But nanosecond level GPS calibration was used by CERN and is being used by Fermilab in the US confirm/extend these results. USNO/NIST is assisting Fermilab in these experiments.
- GPS provides the most widely used means of comparing precise atomic frequency standards operated by timing laboratories which define UTC.
- Future applications of GPS timing, crustal motion measurement, earthquake prediction, exoplanet hunting, etc....

GPS Antenna Electronics

Filter BW and Response Design



- High end GPS monitoring and differential correction services like those operated by JPL and the IGS are used to support high end scientific applications and require high quality GPS measurements to support centimeter navigation and picosecond level timing application.
- In this example we simulate a wide-bandwidth scientific reference station that requires group delay distortion to be controlled to within a few centimeters (30 picosecond).
- In green we show group delay distortion, it is desired to measure GPS in the flattest section of our filter. The largest group delay distortion is near the band pass edge.

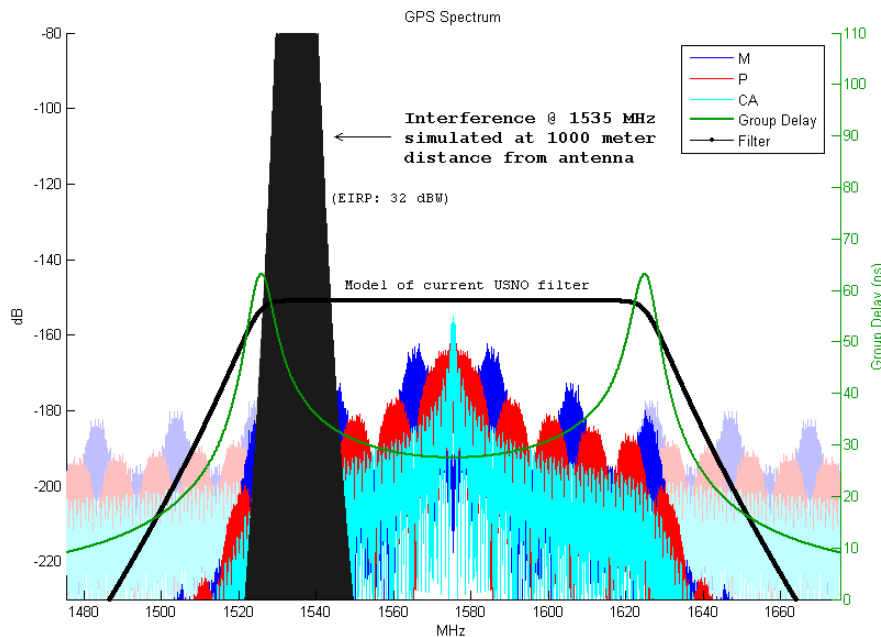


Figure 1

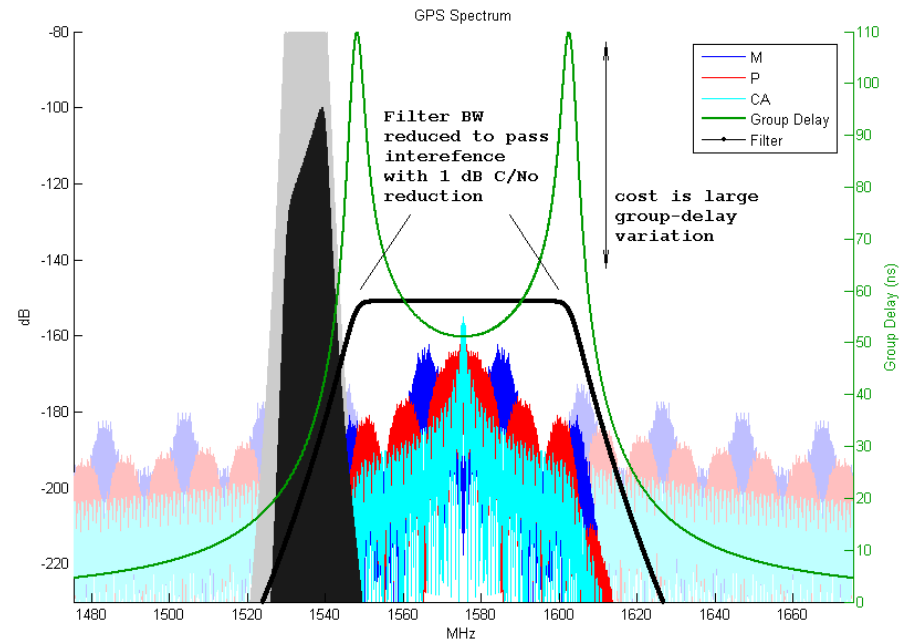
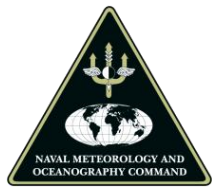


Figure 2

- In the example in Figure 1, we again show a filter with a passband of 100 MHz. This filter is optimized for flat group-delay (< 1 ns) over the 30 MHz band of the P code signals, resulting in an accuracy of < 1 ns and stability of better than 30 picoseconds. But this set of electronics will not function near the terrestrial communication transmitter shown in black. The antenna pre-amplifier will go into saturation and the receiver will not be able to function.
- In the example in Figure 2, we show a filter with a passband of 60 MHz. To adequately attenuate this large interference signal, a narrow band filter is needed, resulting in increased group-delay response error. The severe nonlinear group-delay variations exceed 10 ns across the 30 MHz P code bands, and results in increased errors and degraded timing accuracy.



Conclusion



- The GPS timing services have been used by science and industry for more than 30 years providing an exceptional quality of service.
- GPS timing services provides the global standard for access to precise time supporting:
 - Critical infrastructure
 - Telecommunication,
 - Power Grid,
 - Banking, Financial Transactions (Time Stamps),
 - and Scientific Applications.
- We need to fully understand the criticality of GPS provided timing to the world. USNO would advocate a more focused study on this topic.

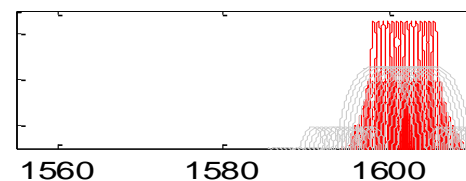
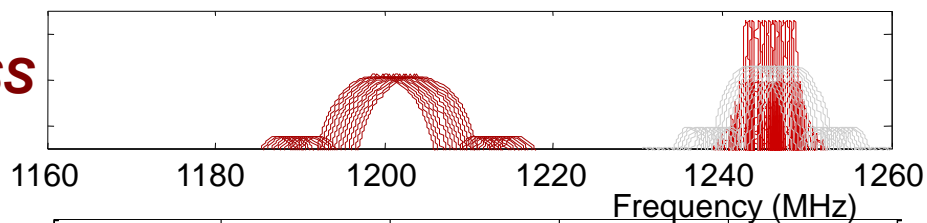


Backup Slide

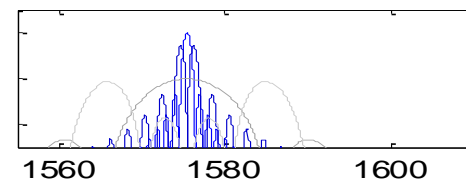
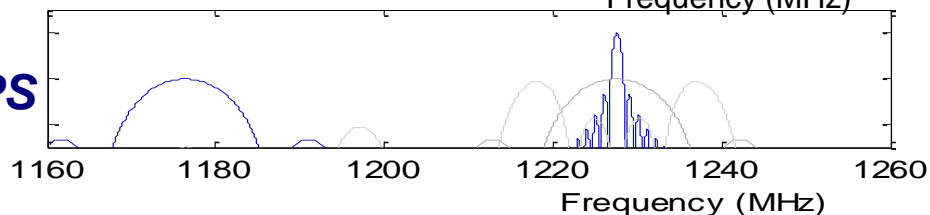


GNSS Currently Planned Signals

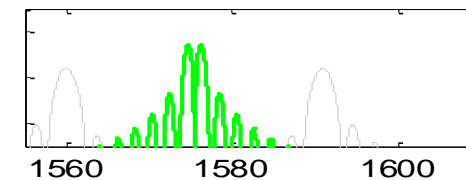
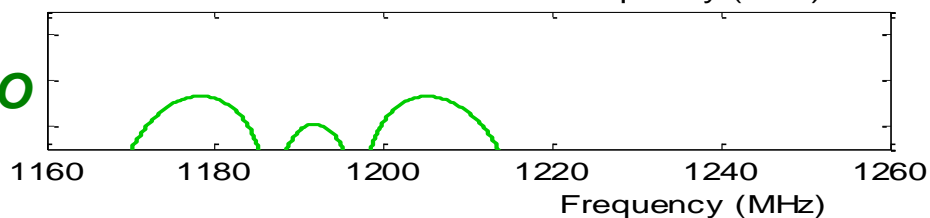
GLONASS



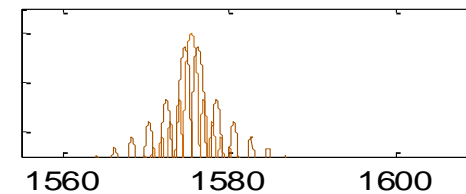
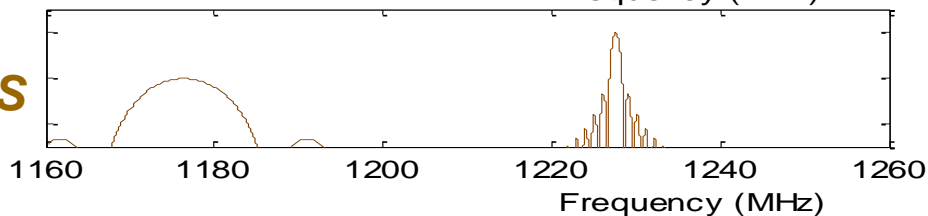
GPS



GALILEO



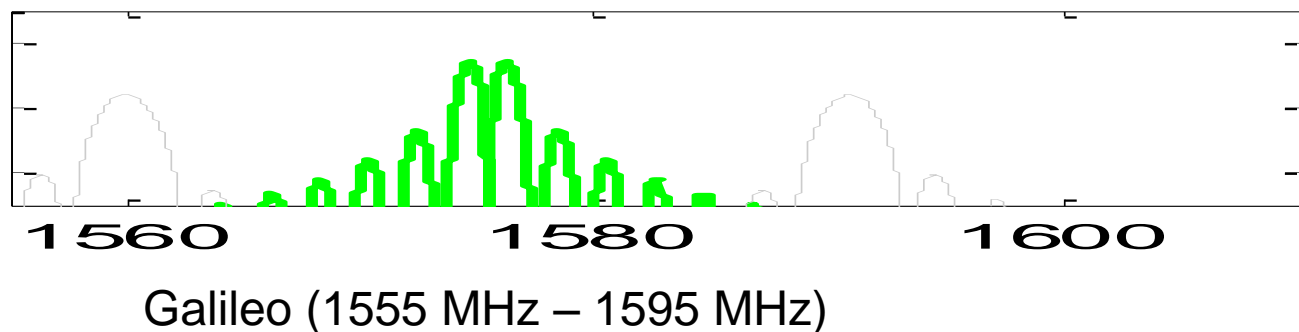
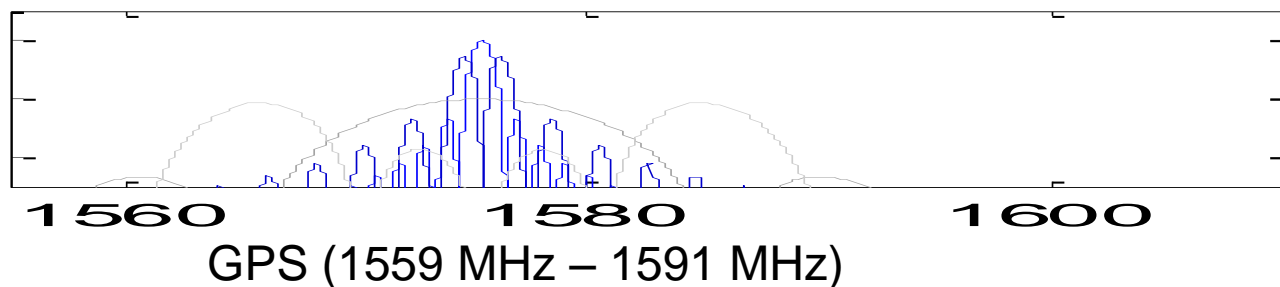
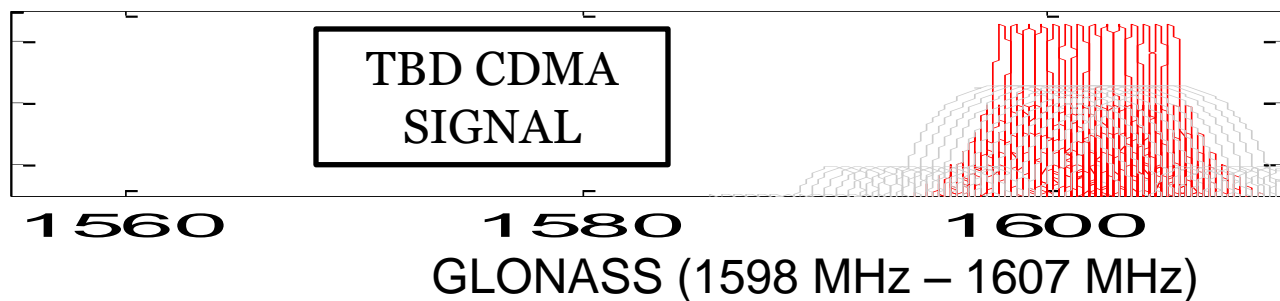
QZSS





GNSS L1 Plan

GLONASS, GPS and Galileo





Multi-GNSS Antenna/Filters

BandWidth needed to support high performance application



- GLONASS extends to 1607 MHz, Galileo extends down to 1555 MHz, with GPS in between.
- Multi-GNSS antenna/filter with fair group delay performance would need an overlap BW of at least 15 MHz, with some loss of performance.
- Thus an L1 filter BW of 82 MHz, extending from 1540 MHz to 1622 MHz, for better performance more BW would be needed (at least 100 MHz).
- Proposed L2/L5 filter BW of 121 MHz, extending from 1149 MHz to 1270 MHz (Galileo E6 would extend the upper frequency to 1310 MHz).



A few Alternative to GPS provided Timing



- Ground based high power transmitters like those used by NDGPS or E-Loran could be used to transmit timing signals supporting microsecond level timing from more than 30 locations across the entire US.
- Use of existing communication infrastructure
 - NTP, IP Networks
 - Land lines (phone lines)
 - IEEE-1588 (PTP)
 - HDTV transmitted signals
 - Optical fiber networks, high speed networks
 - Cell System
- WAAS with MT-12 and directional antenna



GPS Provided Timing Service



■ **UTC Time**

- The UTC broadcast from GPS is referenced to the U. S. Naval Observatory real-time realization of UTC called UTC(USNO) .
- UTC(USNO) is obtained from GPS by subtracting an integral number of seconds (leap seconds) and applying the fine UTC correction information contained in the broadcast navigation data (subframe 4, page 18).

■ **Global Positioning System (GPS) System Time**

- Internal navigation time scale computed from the ensemble of clocks that make up the GPS system and is steered closely to UTC(USNO) modulo one second.

A.4.8 UTC(USNO) Offset Accuracy The SPS SIS NAV message contains offset data for relating GPS time to UTC(USNO). During normal operations, the accuracy of this offset data during the transmission interval is such that the UTC offset error (UTC OE) in relating GPS time (as maintained by the Control Segment) to UTC (as maintained by the U.S. Naval Observatory) is within 40 nanoseconds 95% (20 nanoseconds 1-sigma). See IS-GPS-200 for additional details regarding the UTC(USNO) offset data.



GPS Timekeeping Function



Twofold:

- Navigation Timekeeping:
critical for navigation mission, needed for orbit determination/
prediction and internal satellite clock synchronization,
not intended for timing applications.
- Metrological Timekeeping:
not critical for navigation, but needed to provide a UTC
timing services (time dissemination) to support communication
systems, banking, power grid management, etc...

Navigation Service
Where am I

Timing Service
UTC/PTTI